

Modeling of Habitat and Foraging Behavior of Beaked Whales in the Southern California Bight

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LONG-TERM GOALS

The overall goal of this project is to improve our understanding of beaked whale distribution and foraging behavior and to describe inter-specific differences. We are developing habitat models for multiple beaked whale species in the Southern California Bight using visual and passive acoustic detections acquired from visual and acoustic line transect surveys and autonomous recorders, in correlation with dynamic and static oceanographic habitat variables. We aim to compare habitat models using visual and acoustic line transect data combined with the autonomous acoustic recorder detections with those generated using autonomous acoustic recorder detections alone. The goal is to draw on the strengths of these two beaked whale detection datasets to construct habitat models that are superior to what might be developed using either dataset in isolation. Furthermore, we aim to model the foraging behavior of beaked whales with respect to spatio-temporal occurrence on a diel or seasonal basis and in correlation to oceanographic or geographic variables.

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OBJECTIVES

The objective of this project is to improve our understanding of beaked whale distribution and foraging behavior and to describe inter-specific differences. Knowledge about foraging and habitat preference and potential shifts due to seasonal or oceanographic factors are crucial for conservation and management as well as mitigation of potential effects for naval activities. Previous experience shows that modeling habitat preference of poorly known species, such as beaked whales, can lead to their visual identification during fieldwork and refine understanding of their vocal behavior.

APPROACH

High-Frequency Acoustic Recording Packages (HARPs, Wiggins & Hildebrand 2007) have been collecting acoustic data at 18 sites within the Southern California Bight (SCB) since 2006. Sites ranged from 200 to 3600 m of depth and were located at a variety of environments such as coastal, canyons, basins, islands, shelf break, seamounts and open ocean, covering a broad range of habitats.

Acoustic signal processing for HARP data is performed using the MATLAB (Mathworks, Natick, MA) based custom program Triton (Wiggins & Hildebrand 2007) and other MATLAB custom routines. We expect to find up to ten different beaked whale type signals in the acoustic data (Baumann-Pickering et al. 2013a) and will assume that each unique signal type is species-specific, as has been found for other beaked whale species (Zimmer et al. 2005, Johnson et al. 2006, McDonald et al. 2009, Baumann-Pickering et al. 2010, Rankin et al. 2011, Baumann-Pickering et al. 2013b). Data are screened manually and with automated detectors.

Data from acoustic line-transect surveys (2008-2011) carried out by NOAA Southwest Fisheries Science Center (Jay Barlow) in collaboration with Bio-Waves (Tina Yack), supplies the second beaked whale data set for the habitat modeling effort. These data were post-processed using PAMGUARD and Rainbow Click Software to verify beaked whale detections and assign acoustic detections to species when possible.

Foraging bouts will be automatically detected by investigating consecutive low inter-click intervals (5-10 ms) and low received levels (~20dB lower than prior FM pulses during search and approach phase) (Madsen et al. 2005, Johnson et al. 2006, Baumann-Pickering et al. 2010). Criteria will have to be established for estimating distance of the animals to the recorder to account for detection probability of a foraging event in an echolocation sequence. The relative abundance of foraging events throughout the SCB will be quantified.

The manual and automatic detection time stamps of both HARP data and acoustic line-transect data are stored with the remainder of metadata (e.g. project name, instrument location, detection settings, detection effort) in a database for acoustic metadata management. The database allows storage of acoustic metadata and interacts with outside sources to retrieve physical or biological oceanographic data for habitat model development. A version of the database is in use by the Scripps Whale Acoustics Lab and is in development under a grant issued through the National Oceanographic Partnership Program (NOPP) to Marie Roch (PI), San Diego State University, with Baumann-Pickering, Hildebrand et al. as co-PIs. We will be able to benefit from advances made under the NOPP grant in the management, retrieval, and manipulation of metadata.

WORK COMPLETED

Automatic detectors were run on all HARP data collected between 2006 and 2013 in the SCB, detecting FM pulses from Cuvier's, Blainville's, Stejneger's, and Deraniyagala's beaked whale as well as four signal types of unknown origin (BW40, BW43, BW70, and BWC), described in Baumann-Pickering et al. (2013a). Automatic detectors for Baird's and Longman's beaked whales have not yet been successful. This resulted in detections from long-term data from 126 deployments at 18 sites, a sum of approximately 26 years of cumulative days with recordings, approximately 23.5 years of cumulative continuous acoustic data in the SCB region alone. Manual inspection of all automatic detections was performed with the help of a machine-assisted classification tool (Baumann-Pickering et al. 2013a), which was developed to provide the user with relevant information about known and suspected spectral shapes. Additionally, the same detectors and verification routines were run on an additional fifteen sites within the North Pacific reaching from the Aleutian Islands (north) to Northern Line Islands (south) and from Gulf of California (east) to Northern Mariana Islands (west). The geographic distribution of the different signal types was compared to what is known of the distribution from beaked whale strandings and sightings at sea. There is suggestive evidence to link unknown signal types to certain species of beaked whales. Diel and seasonal patterns were investigated (Baumann-Pickering et al. submitted).

The towed array data 2008 through 2010 have been post-processed and final quantifications of beaked whale encounters have been obtained for the datasets. All acoustic and visual effort for the towed array surveys has been compiled into separate databases. The resulting databases have been formatted in order to use a code developed in R to divide all of the towed array effort into 5 km segments. This code has been successfully applied to the 2008 visual and acoustic datasets. Segmentation of the 2010 and 2011 datasets is currently underway.

Bathymetric variables (depth, slope, aspect, and distance to the 2000 m isobath) are now associated with the HARP deployments and the 2008 visual and acoustic segments using ARCGIS 10.1 tools. Several methods have been explored for expedient querying of satellite data to associate oceanographic variables (i.e. sea surface temperature, sea surface salinity, surface chlorophyll, frontal indices, and upwelling indices) with the datasets. These methods have included R software scripts, Matlab software scripts, and the ARCGIS tool MGET developed by Duke University. We have determined that MGET seems like the most effective way to move forward. The association of the satellite-derived variables with the respective datasets is projected to be completed by mid-October.

Formal statistical analyses to evaluate environmental or other (e.g., temporal, spatial) predictors of beaked whale occurrence are commencing (exploratory at this time, to establish appropriate model structure and develop computer code) and will move forward in earnest as database associations between acoustic recordings and remotely sensed spatial and environmental variables are finalized. Bayesian hierarchical methods will be preferentially applied, as these are well suited for accommodating the two acoustic detection data types (HARP and line-transect data) by linking a single habitat process model to data-specific detection models. Moreover, Bayesian methods are best suited for obtaining best estimates of habitat relationships rather than basing results on the initial assumption (null models) that there are no relationships between detection data and potential predictor variables. The general model structure we are attempting has been outlined in the proposal.

RESULTS

Baird's beaked whale echolocation signals were described based on visual and acoustic surveys as well as HARP data (Baumann-Pickering and Yack et al. 2013c). Two distinct signal types were found, one being a beaked whale-like FM pulse, the other being a dolphin-like broadband click. The median FM inter-pulse interval was 230 ms. Both signal types showed a consistent multi-peak structure in their spectra with peaks at ~ 9, 16, 25, and 40 kHz. Depending on signal type, as well as recording aspect and distance to the hydrophone, these peaks varied in relative amplitude. The description of Baird's echolocation signals will allow for studies of their distribution and abundance using towed array data without associated visual sightings and from autonomous seafloor hydrophones. However, a reliable automatic detector has yet to be developed.

Analysis of the SCB towed array data resulted in a total of 23 Cuvier's beaked whale encounters, 4 Baird's beaked whale encounters, and 3 unidentified Mesoplodon encounters over the 4,875 km of trackline surveyed during the four survey years (Figure 1).

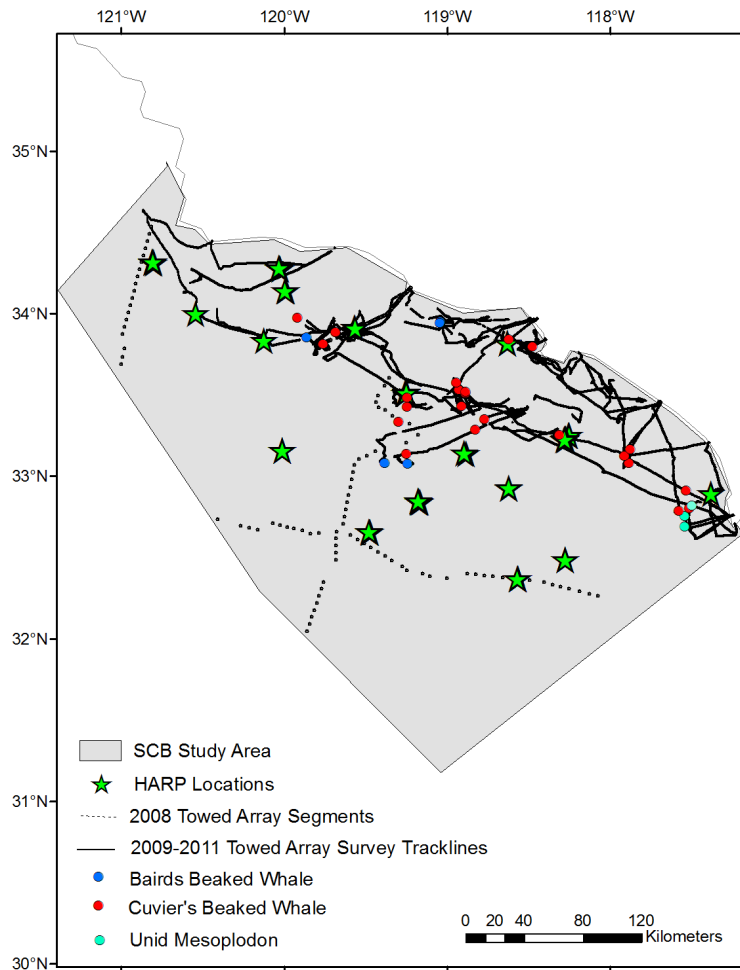


Figure 1: SCB towed array data (black tracklines) from the years 2008-2011 with detections of Baird's (blue), Cuvier's (red), and unidentified beaked whales (turquoise). Grey area denotes polygon over which habitat modeling will be performed.

The detailed analysis of SCB HARP data resulted in ~23,000 acoustic encounters with Cuvier's beaked whales, which was a cumulative continuous recording time of Cuvier's FM pulse echolocation activity of ~60 days. In contrast, the BW43 FM pulse, likely produced by Perrin's beaked whales (Baumann-Pickering et al. 2013a), had 97 acoustic encounters, resulting in a cumulative recording time of ~7 hours. Formal statistical analyses are just getting underway, but it appears that Cuvier's beaked whale FM pulses were predominantly detected at deeper, more southern, and further offshore sites (R, E, H, N, and S, Figure 2A) within the SCB. The BW43 FM pulse signal in comparison had higher detection rates in the more central basins of the SCB (sites H, G2, A2, N, and S, Figure 2B), indicating a possible difference in habitat preference and niche separation, or possibly territorial behavior. It warrants further investigation if this pattern of beaked whale distribution is purely based on bathymetric features or largely driven by water masses within the SCB that determine a certain prey species composition and distribution.

There appears to possibly be a seasonal pattern to the presence of Cuvier's beaked whales in the SCB, exemplified at site H (Figure 3), with generally lower probability of detection during summer and early fall months. However, this may coincide with increased fishing activity and the use of explosives (seal bombs) to deter marine mammals from fishing gear, potentially affecting beaked whale presence in the region. The effect of such anthropogenic activity will have to be taken into account when looking further into seasonality.

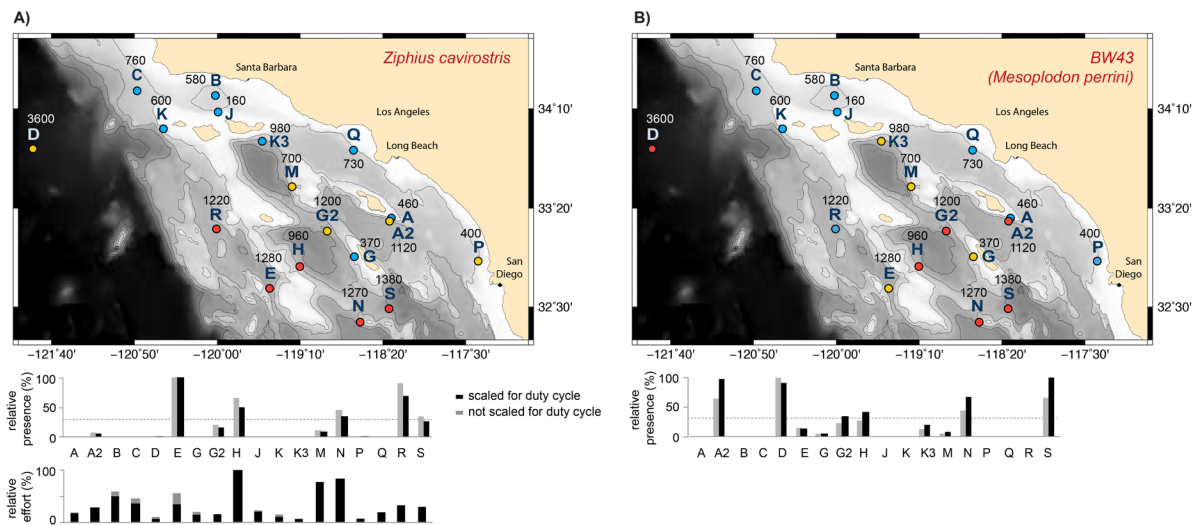


Figure 2: Distribution map of A) *Ziphius cavirostris* (Cuvier's beaked whales) FM pulse and B) BW43 FM pulse detections (likely produced by *Mesoplodon perrini*, Perrin's beaked whales) across the Southern California Bight (SCB). Site name (letter) with depth (m); sites with strong relative beaked whale presence in red (>33% relative presence), sites with low relative presence in yellow, sites with no detections in blue. Presented are automatically detected and manually verified beaked whale detections from 18 sites and 126 deployments. Histograms at the bottom show relative presence across sites and relative recording effort. Some sites were on a duty cycle during some deployment periods (grey bars). This reduced recording time is being adjusted for (black bars).

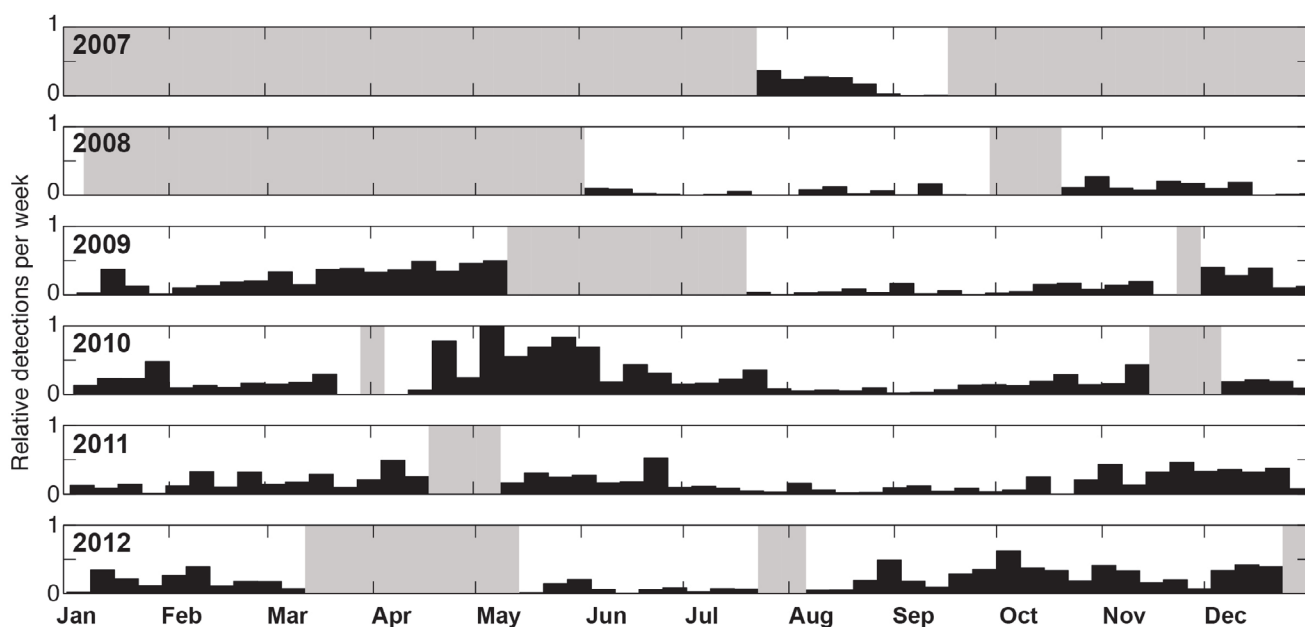


Figure 3: Weekly relative Cuvier's beaked whale FM pulse detections from 2007 until 2012 at site H. There appears to be a seasonal component to the presence of beaked whales at this site with generally lower probability of detection during summer and early fall months.

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IMPACT/APPLICATIONS

The software tool developed to verify automated classification has proven useful for a variety of projects to date. Habitat models will provide knowledge about foraging and habitat preference and potential shifts due to seasonal or oceanographic factors. This is crucial information for conservation and management as well as mitigation of potential effects of naval activities.

RELATED PROJECTS

ONR N001210904 Habitat modeling of fin and blue whales in the Southern California Bight. PI Ana Širović and John Hildebrand. The same HARP sites are used for the modeling, but looking at the low frequency range of the acoustic recordings. Efforts in gathering external oceanographic data as well as thoughts on modeling methods overlap.

ONR N0001411WX21401 Advanced Methods for Passive Acoustic Detection, Classification, and Localization of Marine Mammals. PI Jonathan Klay, Co-PI Marie Roch et al. We will be able to take advantage of expected advances in beaked whale classification through our collaboration with Marie Roch.

NOPP N00014-11-1-0697 Acoustic Metadata Management and Transparent Access to Networked Oceanographic Data Sets. PI Marie Roch, Co-PI Simone Baumann-Pickering, John A. Hildebrand et al. A metadata management system is being developed, which allows access to locally stored acoustic detections and metadata and links in a standardized way to external sources, such as oceanographic or ephemeris data. We will be able to benefit from advances made under the NOPP grant in the management, retrieval, and manipulation of metadata.

PACFLT CESU W9126G-13-2-0016 Passive Acoustic Monitoring for PACFLT Naval Training Ranges. PI John Hildebrand and Co-PI Sean Wiggins. Provides support to collect and analyze acoustic data in the Southern California Range Complex.

REFERENCES

- Baumann-Pickering S, Simonis AE, Wiggins SM, Brownell RL, Hildebrand JA (2013b) Aleutian Islands beaked whale echolocation signals. *Mar Mamm Sci* 29:221-227
- Baumann-Pickering S, Wiggins SM, Roth EH, Roch MA, Schnitzler HU, Hildebrand JA (2010) Echolocation signals of a beaked whale at Palmyra Atoll. *J Acoust Soc Am* 127:3790-3799
- Johnson M, Madsen PT, Zimmer WMX, Aguilar de Soto N, Tyack P (2006) Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. *J Exp Biol* 209:5038-5050
- Madsen PT, Johnson M, de Soto NA, Zimmer WMX, Tyack P (2005) Biosonar performance of foraging beaked whales (*Mesoplodon densirostris*). *J Exp Biol* 208:181-194
- McDonald MA, Hildebrand JA, Wiggins SM, Johnston DW, Polovina JJ (2009) An acoustic survey of beaked whales at Cross Seamount near Hawaii *J Acoust Soc Am* 125:624-627
- Rankin S, Baumann-Pickering S, Yack T, Barlow J (2011) Description of sounds recorded from Longman's beaked whale, *Indopacetus pacificus*. *J Acoust Soc Am* 130:EL339-EL344
- Wiggins SM, Hildebrand JA (2007) High-frequency Acoustic Recording Package (HARP) for broadband, long-term marine mammal monitoring International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables & Related Technologies 2007. IEEE, Tokyo, Japan, p 551-557
- Zimmer WMX, Johnson MP, Madsen PT, Tyack PL (2005) Echolocation clicks of free-ranging Cuvier's beaked whales (*Ziphius cavirostris*). *J Acoust Soc Am* 117:3919-3927

PUBLICATIONS

- Baumann-Pickering S, McDonald MA, Simonis AE, Solsona Berga A and others (2013a) Species-specific beaked whale echolocation signals. *J Acoust Soc Am* 134:2293-2301 [published, refereed]
- Baumann-Pickering S, Simonis AE, Roch MA, McDonald MA and others (submitted) Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific. *PLOS One*
- Baumann-Pickering S, Yack TM, Barlow J, Wiggins SM, Hildebrand JA (2013c) Baird's beaked whale echolocation signals. *J Acoust Soc Am* 133:4321-4331 [published, refereed]

Yack TM, Barlow J, Calambokidis J, Southall B, and Coates S (2013) Identification of previously unknown beaked whale habitat in the Southern California Bight using a towed hydrophone array. J Acoust Soc Am 134:2589-2595 [published, refereed]